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PTO/SB/05 (4/98)
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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No.	
First Inventor or Application Identifier	EDELSON, JONATHAN
Title	HIGH PHASE ORDER INDUCTION MACHINE WITH MESH CONNECTION
Express Mail Label No.	EJ764962796US

JC715 U.S. PTO 09/713654 11/15/00

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents, Box Patent Application, Washington, DC 20231

1. [X] * Fee Transmittal Form *(e.g., PTO/SB/17)* *(Submit an original and a duplicate for fee processing)*
2. [X] Specification [*Total Pages* 18] *(preferred arrangement set forth below)*
   - Descriptive title of the Invention
   - Cross References to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to Microfiche Appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings (*if filed*)
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
3. [X] Drawing(s) *(35 U.S.C. 113)* [*Total Sheets* 3]
4. Oath or Declaration [*Total Pages* 2]
   a. [X] Newly executed (original or copy)
   b. [ ] Copy from a prior application (37 C.F.R. § 1.63(d)) *(for continuation/divisional with Box 16 completed)*
      i. [ ] DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

NOTE FOR ITEMS 1 & 13: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. § 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. § 1.28).

5. [ ] Microfiche Computer Program *(Appendix)*
6. Nucleotide and/or Amino Acid Sequence Submission (*if applicable, all necessary*)
   a. [ ] Computer Readable Copy
   b. [ ] Paper Copy (identical to computer copy)
   c. [ ] Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

7. [ ] Assignment Papers (cover sheet & document(s))
8. [ ] 37 C.F.R.§3.73(b) Statement *(when there is an assignee)* [ ] Power of Attorney
9. [ ] English Translation Document *(if applicable)*
10. [ ] Information Disclosure Statement (IDS)/PTO-1449 [ ] Copies of IDS Citations
11. [ ] Preliminary Amendment
12. [X] Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
13. [X] * Small Entity Statement(s) *(PTO/SB/09-12)* [ ] Statement filed in prior application, Status still proper and desired
14. [ ] Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
15. [ ] Other: ....

16. **If a CONTINUING APPLICATION,** *check appropriate box, and supply the requisite information below and in a preliminary amendment:*
[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No: ______/______
Prior application information: Examiner ______ *Group / Art Unit:* ______

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17. CORRESPONDENCE ADDRESS

[ ] *Customer Number or Bar Code Label* *(Insert Customer No. or Attach bar code label here)* or [X] *Correspondence address below*

Name	Borealis Technical Limited				
Address	23545 NW Skyline Blvd				
City	North Plains	*State*	OR	*Zip Code*	97133-9204
Country	US	*Telephone*	503-621-3286	*Fax*	503-621-3425

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Signature	Jonathan Edelson	*Date*	15 NOV 2000

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TOTAL AMOUNT OF PAYMENT ($) 462.00

Complete if Known	
Application Number	
Filing Date	November 15, 2000
First Named Inventor	EDELSON, Jonathan S.
Examiner Name	
Group / Art Unit	
Attorney Docket No.	

METHOD OF PAYMENT (check one)

1. ☐ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

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☐ Charge Any Additional Fee Required Under 37 CFR §§ 1 16 and 1 17

2. ☒ Payment Enclosed:
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09714365.111500

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	690	201	345	Utility filing fee	345
106	310	206	155	Design filing fee	
107	480	207	240	Plant filing fee	
108	690	208	345	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($) 345

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims	33	-20** =	13	X	9	=	117
Independent Claims	3	- 3** =	0	X	39	=	0
Multiple Dependent						=	

***or number previously paid, if greater, For Reissues, see below*

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	78	202	39	Independent claims in excess of 3
104	260	204	130	Multiple dependent claim, if not paid
109	78	209	39	** Reissue independent claims over original patent
110	18	210	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 117

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	380	216	190	Extension for reply within second month	
117	870	217	435	Extension for reply within third month	
118	1,360	218	680	Extension for reply within fourth month	
128	1,850	228	925	Extension for reply within fifth month	
119	300	219	150	Notice of Appeal	
120	300	220	150	Filing a brief in support of an appeal	
121	260	221	130	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,210	241	605	Petition to revive - unintentional	
142	1,210	242	605	Utility issue fee (or reissue)	
143	430	243	215	Design issue fee	
144	580	244	290	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	690	246	345	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	690	249	345	For each additional invention to be examined (37 CFR § 1.129(b))	

Other fee (specify) ______________________

Other fee (specify) ______________________

* Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($)

SUBMITTED BY				Complete (if applicable)	
Name (Print/Type)	Jonathan S. Edelson	Registration No (Attorney/Agent)		Telephone	503-621-3286
Signature	Jonat Edel			Date	Nov 15, 2000

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STATEMENT CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) & 1.27(b))--INDEPENDENT INVENTOR	Docket Number (Optional)

Applicant, Patentee, or Identifier: EDELSON, Jonathan Sidney

Application or Patent No.:

Filed or Issued: November 15, 2000

Title: High Phase Order Induction Machine with Mesh Connection

As a below named inventor, I hereby state that I qualify as an independent inventor as defined in 37 CFR 1.9(c) for purposes of paying reduced fees to the Patent and Trademark Office described in:

- [ ] the specification filed herewith with title as listed above.
- [X] the application identified above.
- [ ] the patent identified above.

I have not assigned, granted, conveyed, or licensed, and am under no obligation under contract or law to assign, grant, convey, or license, any rights in the invention to any person who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person had made the invention, or to any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern, or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey, or license any rights in the invention is listed below:

- [ ] No such person, concern, or organization exists.
- [X] Each such person, concern, or organization is listed below.

Borealis Technical Limited

Separate statements are required from each named person, concern, or organization having rights to the invention stating their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

Jonathan S. Edelson		
NAME OF INVENTOR	NAME OF INVENTOR	NAME OF INVENTOR
Jonat Edelson		
Signature of inventor	Signature of inventor	Signature of inventor
November 15, 2000		
Date	Date	Date

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STATEMENT CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) & 1.27(c))--SMALL BUSINESS CONCERN

Docket Number (Optional)

Applicant, Patentee, or Identifier: EDELSON, Jonathan Sidney
Application or Patent No.:
Filed or Issued: November 15, 2000
Title: High Phase Order Induction Machine with Mesh Connection

I hereby state that I am
☐ the owner of the small business concern identified below:
☒ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF SMALL BUSINESS CONCERN Borealis Technical Limited

ADDRESS OF SMALL BUSINESS CONCERN Suite 3C Centre Plaza
Horse Barrack Lane, PO Box 926 Gibraltar

I hereby state that the above identified small business concern qualifies as a small business concern as defined in 13 CFR Part 121 for purposes of paying reduced fees to the United States Patent and Trademark Office, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time, or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby state that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention described in:

☒ the specification filed herewith with title as listed above.
☐ the application identified above.
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If the rights held by the above identified small business concern are not exclusive, each individual, concern, or organization having rights in the invention must file separate statements as to their status as small entities, and no rights to the invention are held by any person, other than the inventor, who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d), or a nonprofit organization under 37 CFR 1.9(e).

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Separate statements are required from each named person, concern or organization having rights to the invention stating their status as small entities. (37 CFR 1.27)

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NAME OF PERSON SIGNING Rodney T. Cox
TITLE OF PERSON IF OTHER THAN OWNER CEO/Chairman
ADDRESS OF PERSON SIGNING 27 Heathway Court, London NW3 7TS ENGLAND
SIGNATURE [signature] DATE Nov 15, 2000

PROVISIONAL PATENT APPLICATION OF
JONATHAN SIDNEY EDELSON
FOR
HIGH PHASE ORDER MOTOR WITH MESH CONNECTED WINDINGS

TECHNICAL FIELD OF THE INVENTION

The present invention relates to motors and their inverter drives.

BACKGROUND OF THE INVENTION

An induction motor is commonly driven by an inverter. An inverter is a device capable of supplying alternating current of variable voltage and variable frequency to the induction motor, allowing for control of machine synchronous speed and thus of machine speed. The inverter may also be used with AC induction generators, and can cause an AC induction motor to act as a generator for braking applications.

In many cases, the cost of the inverter is considerably greater than the cost of the motor being supplied. It is thus necessary to minimize the size of the inverter power electronics in order to control system cost.

Whereas the induction machine itself may have substantial overload capability, and may carry currents of the order of five to ten times full rated current for periods measured in minutes, the overload capability of the inverter electronics is severely limited. Exceeding the voltage or current ratings of the inverter electronics will swiftly cause device failure. Commonly, inverter electronics is specified such that it can tolerate 150% of nominal full load current for 1 minute, and for any given motor, and inverter will be selected which has the same nominal current capability as that of the motor.

Voltage is set internally by the inverter system or by the rectified supply voltage. Voltage overload is normally not

specified, and will cause near instantaneous destruction of semiconductor elements. The voltage ratings of the semiconductors instead set the maximum output voltage of the inverter system, and an inverter will be selected which has a maximum output voltage that matches the operating voltage of the motor at full speed.

With any reasonably sized inverter, substantial motor overload capabilities remain untapped.

In many traction application, there is limited available electrical power. Thus requirements for high overload capability can only be met at low speed, where high torque is required for starting, but reduced speed means that mechanical power output is still low. Such low speed torque requirements require high current to flow though the motor, but do not require high operating voltage. It is thus possible to trade high speed operating capability for low speed overload capability at the design stage of a motor drive system.

By increasing the number of series turns in the motor windings, higher slot current may be achieved with the same terminal current, thus permitting the same inverter to provide greater overload current to the motor. This increase in overload capability comes at a substantial cost. The increased number of series turns means that the motor operating voltage is increased, operation at high speed is prevented. Most motors are designed for dual voltage operation, through the expedient of operating various subcircuits of the motor in series or parallel connection. The change between series and parallel connection may be accomplished though suitable contactor arrangements, permitting the motor to be operated with a higher number of series turns at low speed, and a lower number of series turns at high speed. For a simple three phase induction machine system, such a system would require at least two single-pole three-phase contactors, and would only offer a factor of 1.7 increase in low

speed overload capability. With three contactors, a factor of two change is possible.

The change in series turns may be considered a change in induction machine impedance, or current versus voltage relation. Normally, an induction machine will have a fixed relationship between synchronous speed and impedance, characterized by the Volts/Hertz ratio. For a given inverter and machine frame, a machine wound with a higher Volts/Hertz ratio will have a lower maximum speed, but higher peak low speed torque.

It is thus necessary to provide for an induction machine drive system in which the induction machine presents a variable Volts/Hertz ratio to the inverter. For high speed operation, the Volts/Hertz ratio would be adjusted to a low value, in order to maintain a suitable induction machine operational voltage. For low speed operation, the Volts/Hertz ratio would be adjusted to a higher value, so as to permit high overload torque operation.

SUMMARY OF THE INVENTION

From the foregoing it will be appreciated that a serious need exists for a motor drive system that has variable impedance. The present invention provides a drive system that can achieve high torque overload at low speeds whilst also being capable of providing sufficient voltage for high speed applications. In the present invention a high phase order induction machine is used with each phase terminal separately connected to an inverter output. The windings of the induction machine are wound as full span connected windings, and the motor terminals are connected with a mesh connection to produce a low impedance output. The inverter is capable of operating with a variable phase sequence that changes the effective impedance of the motor.

A technical advantage of the present invention is that impedance may be electronically varied. This eliminates the need

and cost of mechanical contactor arrangements and allows greater variability in impedance.

A further technical advantage is that a motor may achieve substantially high torque at low speeds, whilst also being able to operate at high speeds.

A yet further technical advantage is that an inverter output may be better exploited by a motor.

Further technical advantages will become apparent from a consideration of the figures and the ensuing descriptions.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete explanation of the present invention and the technical advantages thereof, reference is now made to the following description and the accompanying drawings, in which:

Fig. 1 illustrates how the winding terminals of a polyphase motor may be connected to a polyphase inverter.

Fig 2 illustrates a plurality of ways in which the polyphase inverter may be connected to a polyphase motor.

Fig. 3 illustrates how winding terminals of a motor connected to a polyphase inverter in a particular fashion may be driven by the inverter with various phase angles.

DETAILED DESCRIPTION OF THE INVENTION

In the method and apparatus of the present invention, a high phase order induction motor is connected to a high phase count inverter. Rather than using a star connection for the high phase count machine, the motor is connected mesh, meaning that the two winding terminals of each motor phase are each connected to separate inverter output terminals, whilst each inverter output terminal is connected to two motor phase terminals. The three

phase mesh connection is well known in the art, and is commonly known as a delta connection.

In an induction machine, each phase winding set can be described by two terminals. There may be a larger number of terminals, but these are always grouped in series or parallel groups, and the entire set can be characterized by two terminals. In a star connected machine, one of these terminals is driven by the inverter or power supply, while the other terminal is connected to the machine neutral point. All current flows through one terminal, through the neutral point into other windings, and though the driven terminals of the other phases. In a mesh connected machine, these two terminals are connected directly to two different supply points. An example of how this may be done is shown in **Fig 1**, in which the stator slots **4** are shown as straight lines running down the inside of the stator, and inverter terminals **2**, are shown as circles, alongside which is marked phase angles of each of the inverter terminals. Electrical connections **3** between the winding terminals in stator slots **4** and inverter terminals **2** are represented by dashed lines. Two winding halves are displayed opposite one another, and are actually joined to one another, although this is not shown. The configuration describes a 9 phase machine connected with an S=3 connection - identical to **Fig 2e**.

In contrast to three phase systems, in which there are only three inverter terminals and six motor windings terminals, in a high phase count system with N phases, there are N inverter terminals and 2N motor windings terminals. There are thus a substantial number of choices for how an N phase system may be mesh connected. This set of choices is greatly reduced by rotational symmetry requirements, specifically each winding must be connected to two inverter terminals with the same electrical angle difference between them as for every other winding.

A simple graphical schematic of the permissible inverter to motor windings connections may thus be described, for a polyphase

motor having N phases. **Fig. 2** shows N evenly spaced points and a center point. Each of these points represents an inverter terminal **2**, to which one of the terminals of each of one or more motor windings **1** may be connected. Permissible connections of the N phase windings are either from the center point, to each of the N points on the circle (this being the star connection shown as **Fig. 2a**) or from each of the N points to another point S points distant in the clockwise direction, where S represents the number of skipped points (inverter terminals). It will be noted that for each S from 0 to N/2-1 there is a corresponding S from N/2-1/2 to N that produces a mirror image connection.

Fig. 2 shows all permissible connections for a 9 phase system from S=0 to S=N/2-1 as well as the star connection. Noted on the star connection diagram are the relative phase angles of the inverter phases driving each terminal. For a given inverter output voltage, measured between an output terminal and the neutral point, each of these possible connections will place a different voltage on the connected windings. For the star connection, the voltage across the connected windings is exactly equal to the inverter output voltage. However, for each of the other connections, the voltage across a winding is given by the vector difference in voltage of the two inverter output terminals to which the winding is connected. When this phase difference is large, then the voltage across the winding will be large, and when this phase difference is small, then the voltage across the winding will be small. It should be noted that the inverter output voltage stays exactly the same in all these cases, just that the voltage <u>difference</u> across a given winding will change with different connection spans. The equation for the voltage across a winding is given by: 2*sin((phasediff)/2)*Vout where phasediff is the phase angle difference of the inverter output terminals driving the winding, and V is the output to neutral voltage of the inverter.

Thus, referring to **Fig. 2**, when S=0, the phase angle difference is 40 degrees, and the voltage across a winding is 0.684Vout. When S=1, the phase angle difference is 80 degrees, and the voltage across the winding is 1.29Vout. When S=2, the phase angle difference is 120 degrees, and the voltage across the winding is 1.73Vout. Finally, when S=3, the phase angle difference is 160 degrees, and the voltage across the winding is 1.97Vout. For the same inverter output voltage, different connections place different voltage across the windings, and will cause different currents to flow in the windings. The different mesh connections cause the motor to present a different impedance to the inverter.

To deliver the same power to the motor, the same voltage would have to be placed across the windings, and the same current would flow through the windings. However, for the S=0 connection, to place the same voltage across the windings, the inverter output voltage would need to be much greater than with the S=3 connection. If the inverter is operating with a higher output voltage, then to deliver the same output power it will also operate at a lower output current. This means that the S=0 connection is a relatively higher voltage and lower current connection, whereas the S=3 connection is a relatively lower voltage, higher current connection.

The S=0 connection is desirable for low speed operation, where it increases the overload capabilities of the drive, and permits much higher current to flow in the motor windings than flow out of the inverter terminals. The S=3 connection is desirable for high speed operation, and permits a much higher voltage to be placed across the windings than the inverter phase to neutral voltage. This change in connection is quite analogous to the change between star and delta connection for a three phase machine, and may be accomplished with contactor apparatus. However the number of terminals renders the use of contactors to change machine connectivity essentially impracticable.

There is, however, an additional approach available with high phase order inverter driven systems.

The inverter, in addition to being an arbitrary voltage and current source, is also a source of arbitrary phase AC power, and this output phase is electronically adjustable. Any periodic waveform, including an alternating current may be described in terms of amplitude, frequency, and phase; phase is a measure of the displacement in time of a waveform. In a polyphase inverter system, phase is measured as a relative phase displacement between the various outputs, and between any pair of inverter terminals, an electrical phase angle may be determined. In the case of conventional three phase systems, this electrical phase angle is fixed at 120 degrees. However in polyphase systems this phase angle is not fixed. Thus, while the machine terminals 1..9 may be fixed in their connection to inverter terminals 1..9, the phase relation of the inverter terminals connected to any given motor winding terminals is not fixed. By changing the inverter phase relation, the impedance that the motor presents to the inverter may be changed. This may be done without contactors.

With Reference to **Fig. 3**, a 9 phase machine is connected to the inverter system using the S=3 mesh. One terminal of each of two windings **1** is connected to each inverter terminal **2**. When driven with 'first order' phase differences, then the results are as described above for the S=3 mesh. However, if the phase angles are adjusted by multiplying each absolute phase reference by a factor of three, then the phase differences placed across each winding become the same as those found in the S=2 case, although the topological connectivity is different. If the phase angles are adjusted by a multiplicative factor of five, then the voltages across windings become like those of the S=1 case, and with a multiplicative factor of seven, the voltages become like those of the S=0 case. A multiplicative factor of nine causes all phases to have the same phase angle, and places no voltage difference across the winding.

These changes in phase angle are precisely the changes in phase angle used to change the operating pole count of a high phase order induction machine, as described in others of my patent applications and issued patents.

If a high phase count concentrated winding induction machine is operated by an inverter, but is connected using a mesh connection, then changes in pole count of the machine will be associated with changes in machine effective connectivity. These changes in effective connectivity permit high current overload operation at low speed, while maintaining high speed capability, without the need for contactors or actual machine connection changes.

Of particular value are machines connected such that the fundamental, or lowest pole count, operation is associated with a relative phase angle across any given winding of nearly, but not exactly, 120 degrees. In these cases, altering the output of the inverter by changing the absolute phase angles by a multiplicative factor of three, which may also be described as operation with the third harmonic will result in the relative phase angle across any given winding becoming very small, and causing large winding currents to flow with low inverter currents. A particular example would be a 34 slot, 17 phase machine, wound with full span, concentrated windings, to produce a two pole rotating field. The winding terminations are connected to the inverter using the S=5 mesh. The relative phase angle of the inverter outputs placed across any given winding would be 127 degrees, and the voltage placed across this winding relative to the inverter output voltage is 1.79 times the inverter output voltage. If the machine is then operated with a third harmonic waveform, it will operate as a six pole machine. The relative phase angle across any given winding is now 127*3mod 360= 21 degrees, and the voltage placed across the winding relative to the inverter output voltage is 0.37 times the inverter output voltage. Simply by changing the inverter drive angles, the Volts/Hertz

relationship of the motor is increased, and inverter limited overload capability is enhanced.

To determine the ideal S, the number of skipped inverter terminals between the winding terminals of each phase of the motor, which would result in the greatest change of impedance when the inverter drives the motor with substantial third harmonic, one would use the formula (N/3)-1, rounded to the nearest integer, for values of N (number of phases in motor) not divisible by 3. When N is divisible by 3, one would use the formula N/3 to determine the skip number.

Other connectivity is certainly possible. The connection described above will tend to maximize machine impedance for the third harmonic, but will actually decrease machine impedance for fifth harmonic. A connection that most closely approximates full bridge connection, e.g. the S=7 connection for the 17 phase machine described above, will show gradually increasing machine impedance for the 3^{rd}, 5^{th}, 7^{th}, 9^{th}, 11^{th}, 13^{th}, and 15^{th} harmonics. This may be of particular benefit, for example, with machines operated with square wave drive. Operation with high pole counts is not generally considered preferable, however it may be of benefit in the particularly desirable case of operating at high overload and low speed. The number of slots is not restricted, nor are the number of phases or poles. In order to determine the value of S (skip number) in the winding to inverter connections, one may use the formula (N-3)/2, when N (number of motor phases) is an odd number. When N is even by may be divided into subsets of odd phase counts, the formula may similarly be used for the odd subsets.

The general principal of the present invention may be utilized for the operation of high phase order induction machines including motors, generators, and motor/generators, and may also be utilized for different loads which require variable frequency supply, e.g. induction heating applications. Also, saturation of single harmonics are not required, and an exceedingly variable

impedance may be produced by the gradual and increasing superimposition of harmonic content, for example, of the third harmonic.

The present invention has been described with regard to rotary induction motors, however it may be implemented with linear induction motors too, using similar techniques for changing winding impedance. Where the windings of a linear or also of a rotary induction motor comprise single inductors instead of coils, then inverter output phase angle may be altered by an even multiplicative factor in order to effect impedance changes. In some cases, the inverter may even multiply each phase angle by a fractional factor to vary the impedance of the motor.

The present invention has been described as a way of connecting a polyphase motor to a polyphase inverter. Furthermore, there have been described methods of electrically varying the impedance, and methods to design the windings to inverter connections in order to optimize such impedance variation. In this way, the same motor may act as though it has a high number of series turns for low speed operation, being supplied with high voltage and low current, yet still be able to reach high speeds as though the motor has relatively few series turns. Also, contactor arrangements are not essential However, an additional facet of the present invention provides for a plurality of inverter to windings connections to be set up in the same machine, e.g. in 9 phase machine, S=0 and S=3 could both be independently connected or available to be connected. Contactors or switches would be arranged in each terminal to change the way the windings are connected to the inverter terminals based on the dual arrangements set up in the machine. This is an example of another way in which the motor impedance may be controlled according to the present invention.

The word "terminal" has been used in this specification to include any electrically connected points in the system - this may be a screw, for example, or any electrical equivalent, for

example, it may simply comprise a wire connecting two components in a circuit.

In a similar sense, inverter output elements are commonly half bridges, but they may alternatively comprise other switching elements. One embodiment of the present specification has described two winding terminals connected to a single inverter terminal. The single inverter terminal referred to is intended to also include electrical equivalents, such as a device made of two inverter terminals that are electrically connected together.

Thus, it is apparent that there has been provided, in accordance with the present invention, a method and apparatus for a high phase order motor with mesh connected windings that satisfies the advantages set forth above. Thus, the mesh connection and the implementation techniques of the present invention may be used in virtually all motor applications.

While this invention has been described with reference to numerous embodiments, it is to be understood that this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments will be apparent to persons skilled in the art upon reference to this description. It is to be further understood, therefore, that numerous changes in the details of the embodiments of the present invention and additional embodiments of the present invention will be apparent to, and may be made by, persons of ordinary skill in the art having reference to this description. It is contemplated that all such changes and additional embodiments are within the spirit and true scope of the invention as claimed below.

All publications and patent applications mentioned in this specification are indicative of the level of skill of those skilled in the art to which this invention pertains. All publications and patent applications are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference.

CLAIMS:

I claim:

1. A high phase order induction machine drive system, comprising

a) an induction motor having more than three phases, and having at least two terminals for each phase, and

b) an inverter system for the synthesis of alternating current of as many phases as the number of phases that said induction motor comprises, said inverter system electrically connected to said terminals of said phases of said induction motor with a mesh connection, said alternating current of said phases of said inverter system having variable electrical phase.

2. The high phase order induction machine drive system of claim **1** wherein said at least two terminals comprise two terminals.

3. The high phase order induction machine drive system of claim **2** wherein the inverter is connected to said terminals with half bridge inverter outputs.

4. The high phase order induction machine drive system of claim **2** wherein said motor is wound with full span concentrated windings.

5. The high phase order induction machine drive system of claim **4** wherein said half bridge inverter outputs are connected with a mesh connection to said winding terminals.

6. The high phase order induction machine drive system of claim **2** wherein said half bridge inverter outputs are connected with a mesh connection to said winding terminals.

7. The high phase order induction machine drive system of claim **2** wherein said mesh connection having the highest possible skip number that may be rotationally applied to said terminals.

8. The high phase order induction machine drive system of claim **2** wherein said mesh connections arranged to drive current of as close to 120 electrical degrees as possible to each phase, for the number of phases comprised by said motor.

9. The high phase order induction machine drive system of claim **8** wherein said control electronics for adjusting the electrical angles of the driving connections between the inverter and the motor being arranged to drive the third harmonic of the fundamental current to the motor terminals in response to a signal to increase the impedance of the motor.

10. The high phase order induction machine drive system of claim **9** wherein said motor comprising 17 phases and wherein said mesh connection arranged with a skip number of 5 between each pair of terminals of the same winding.

11. The high phase order induction machine drive system of claim **2** wherein said control electronics are designed to drive current of increased electrical angles to said terminals in response to a signal to increase the impedance of the motor

12. The high phase order induction machine drive system of claim **2** wherein said more than three phases being an odd number of phases and wherein each phase comprises two terminals and wherein the number of connected terminals equals N, and wherein the two terminals of each phase are separated in one circular direction by 1/2(N-3) other connected terminals.

13. The high phase order induction machine drive system of claim **11** wherein said control electronics are arranged to increase the electrical angles of the current to the terminals in response to a signal to increase the impedance of the motor

14. The high phase order induction machine drive system of claim **7** wherein said control electronics are designed to multiply the electrical angle of each of the terminals by (N-2) in response to a signal to increase the impedance of the motor.

15. The high phase order induction machine drive system of claim **7** wherein said control electronics are designed to multiply the electrical angle of each of the terminals by the same number in response to a signal to increase the impedance of the motor.

16. The high phase order induction machine drive system of claim **2** wherein said mesh connection comprises one inverter terminal connected to two adjacent winding terminals.

17. The high phase order induction machine drive system of claim **2** further comprising contactors for the switching to a second mesh connection of a different skip number from the first mesh connection, whereby the impedance of the motor may be mechanically varied.

18. A method for varying the impedance of a motor, comprising

a) connecting a motor having more than three phases with a mesh connection to an inverter system, and,

b) driving the terminals of the mesh connection by the inverter, and

c) varying the inverter output phase angles of the terminals

19) The method of claim **18** wherein said step of varying the inverter output phase angles of the terminals comprising multiplying each of the phase angles by the same number to increase the impedance of the motor.

20) The method of claim **19** wherein the number of phases being odd and equaling N, and wherein said step of multiplying the phase angles by the same number comprises multiplying the phase angles by an integral multiple.

21) The method of claim **19** wherein the number of phases being odd and equaling N, and wherein said step of multiplying the phase angles by the same number comprises multiplying the phase angles by an odd integral multiple.

22) The method of claim **19** wherein the number of phases being odd and equaling N, and wherein said step of multiplying the phase angles by the same number comprises multiplying the phase angles by (N-2).

23) The method of claim **19** wherein the step of multiplying the phase angles by the same number comprising multiplying the

phase angles by the product of the formula ((360N/R) +1)/S+1, where N is any integer, R is the angle between adjacent terminals in degrees, and S is the skip number between the two terminals of each phase.

24) The method of claim **18** wherein the step of varying the inverter phase angles of the terminals comprising the step of providing the terminals with the odd order harmonic that corresponds most closely with required impedance.

25) The method of claim **18** wherein the step of varying the inverter phase angles of the terminals comprising the step of providing the terminals with increasing saturation of an odd order harmonic.

26) The method of claim **18** wherein the step of varying the inverter phase angles of the terminals comprising the step of providing the terminals with a plurality of odd order harmonics.

27) The method of claim **18** wherein said step of connecting is done by connecting the windings to the inverter terminals with a mesh connection of the type that will cause the phase angle across each winding to be nearly but not exactly 120 degrees of fundamental current, and wherein said step of varying the inverter output phase angles of the terminals is done by adding third harmonic content to the drive waveform of the inverter.

28) The method of claim **18** wherein said step of adding third harmonic is done by gradually increasing the saturation of third harmonic content in the waveform.

29) The method of claim **18** wherein said step of connecting is done by connecting the windings to the inverter terminals with a mesh connection of the type that will cause the largest phase angle possible across each winding of fundamental current.

30) The method of claim **18** wherein said step of varying the inverter output phase angles of the terminals is done by adding all of the odd order harmonics to the inverter drive waveform up to the number of phases of the motor.

31) A high phase order motor connected to inverter output elements with a mesh connection.

32) The high phase order motor of claim **31**, in which the skip number of the mesh connection is the highest skip number possible which allows for rotational symmetry.

33) The high phase order motor of claim **31**, in which the skip number of the mesh connection is zero.

HIGH PHASE ORDER MOTOR WITH MESH CONNECTED WINDINGS

Abstract

A high phase order induction machine drive system, comprising an induction motor having more than three phases, and having at least two terminals for each phase, and wherein each terminal is connected to at least one terminal of another phase, and an inverter for synthesis of power of a plurality of phases, drivingly connected to each of the set of connected terminals, and control electronics for adjusting the phase angles of the inverter to the connected terminals to change the impedance of the motor.

Fig. 1

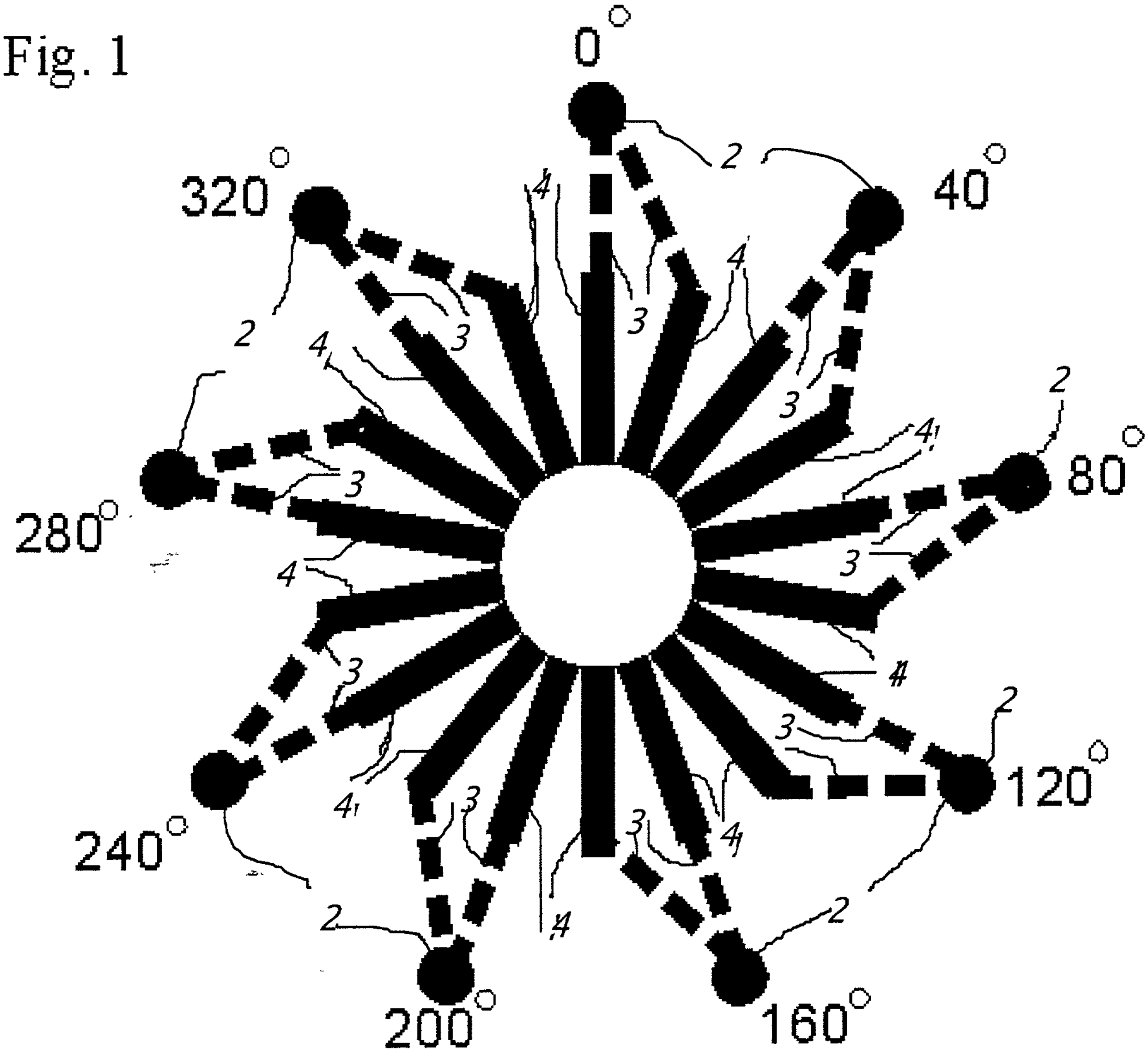
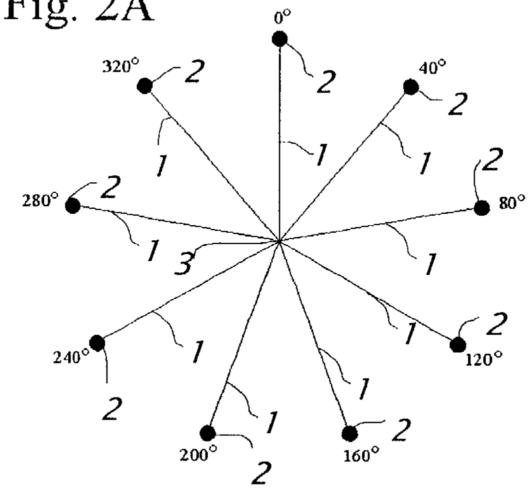
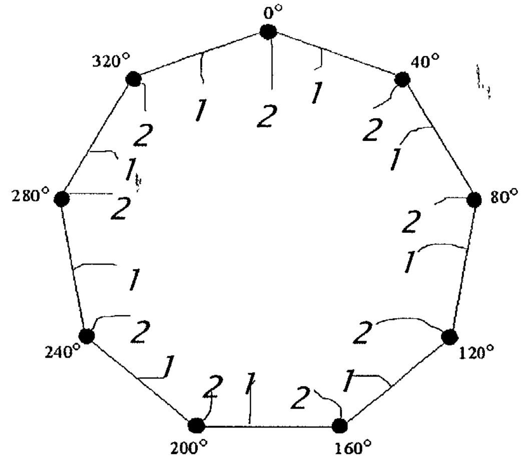


Fig. 2A



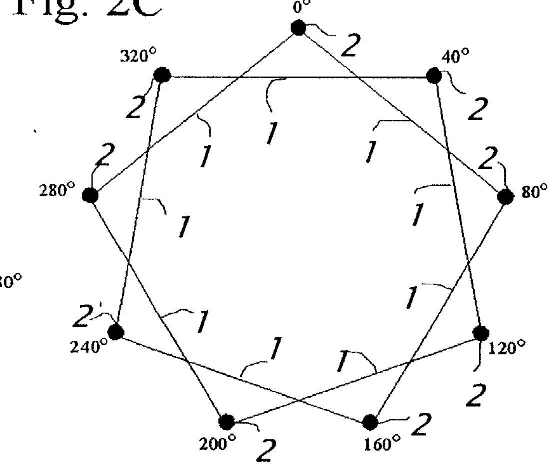
STAR

Fig. 2B



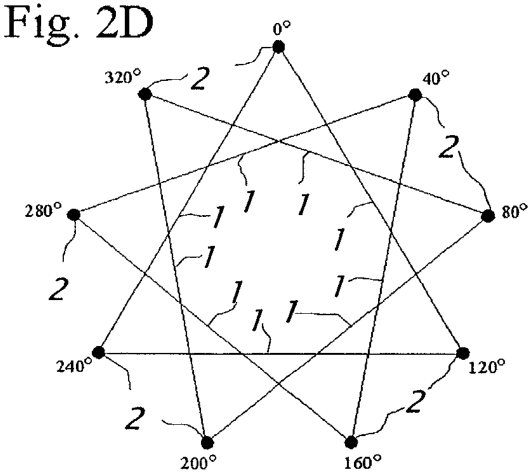
S=0

Fig. 2C



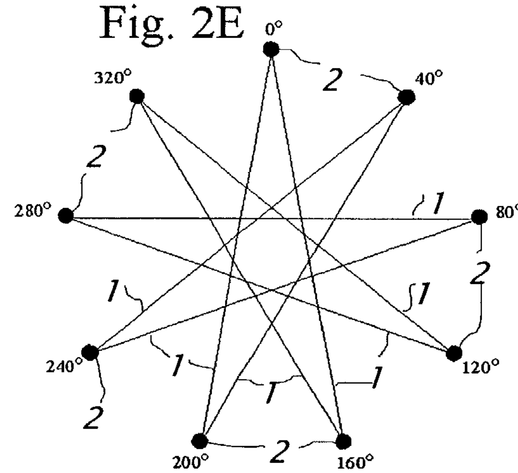
S=1

Fig. 2D



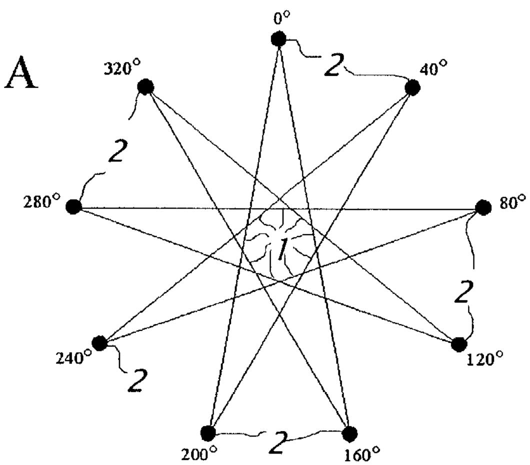
S=2

Fig. 2E



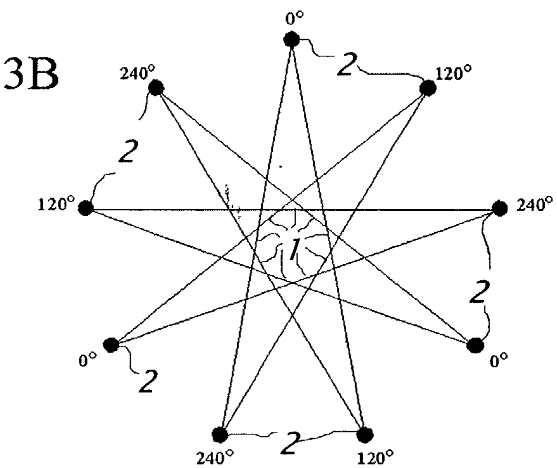
S=3

Fig. 3A



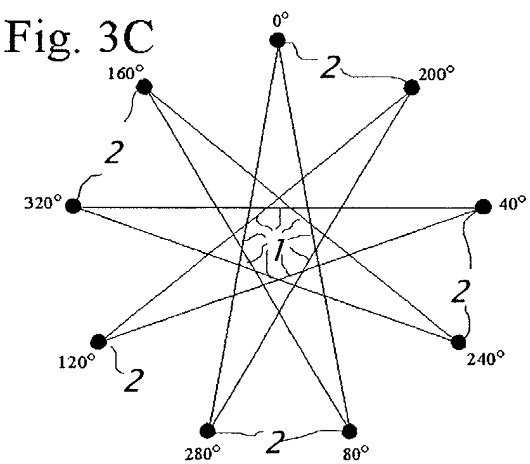
Fundamental

Fig. 3B



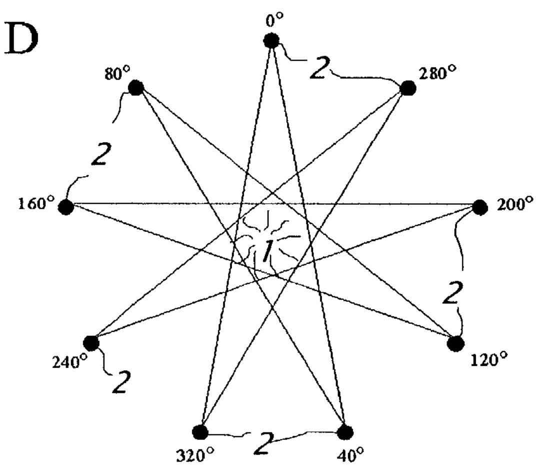
Third Harmonic

Fig. 3C



Fifth Harmonic

Fig. 3D



Seventh Harmonic

Please type a plus sign (+) inside this box → [+]

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DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

[X] Declaration Submitted with Initial Filing OR [ ] Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)

Attorney Docket Number	
First Named Inventor	EDELSON, JONATHAN
COMPLETE IF KNOWN	
Application Number	/
Filing Date	November 15, 2000
Group Art Unit	
Examiner Name	

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

High Phase Order Induction Machine with Mesh Connection

(Title of the Invention)

the specification of which

[X] is attached hereto

OR

[ ] was filed on (MM/DD/YYYY) [ ] as United States Application Number or PCT International Application Number [ ] and was amended on (MM/DD/YYYY) [ ] (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]

[ ] Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	
60/242,622	10/23/00	[ ] Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

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I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number *(if applicable)*

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Name	Registration Number	Name	Registration Number

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

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☐ Additional inventors are being named on the ____supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto